Ripple Morphodynamics in Wave-Current Boundary-Layer Flows

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LONG-TERM GOALS

The long-term goal of our research is to improve our understanding of ripple morphodynamics in wave-current, boundary-layer flows. Our main focus is on the study of sediment transport in oscillatory boundary layers in the presence of unidirectional currents and the associated bed morphology (i.e. 2D and 3D ripples).   To this end, both wave-induced and wave-current-induced oscillatory flow conditions are simulated in a wave-current flume and in a Large Oscillating Water Sediment Tunnel (LOWST) built and equipped with an ONR grants DURIP Awards N00014-01-1-0540 and N00014-06-1-0661.

OBJECTIVES

Specific objectives for this effort are as follows:

1) To assess experimentally equilibrium combined-flow bed configurations (i.e. plane bed, 2D ripples, 3D ripples) developed over a wide range of oscillatory and unidirectional velocity components, oscillation periods, and sediment grain sizes.

2) To study the flow field and grain dynamics for rippled beds and sheet flow conditions. In particular, the role of ripple-generated turbulence and grain fluid interaction.

3)   To assess the role of ripple morphology on sediment entrainment into suspension and bed roughness.

APPROACH

Our approach has been mainly an experimental one. We have conducted laboratory experiments with two special-purpose facilities. One facility is the Large Oscillating Water Sediment Tunnel (LOWST) constructed with DURIP support. LOWST can reproduce field-like conditions near the sea bed. The second facility is a multipurpose wave-current flume which is 4 feet (1.20 m) deep, 6 feet (1.8 m) wide, and 161 feet (49.2 m) long.   It has a 30 cm deep movable sediment bed where the morphodynamics of ripples and sand-waves can be studied under controlled conditions. To characterize the evolution of ripples in both space and time, we have used acoustic sensors which have been employed by our group in a related study on mine burial study. The flow field and the fluid-grain interaction are being studied with the help of particle-image-velocimetry (PIV) and particle tracking

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velocimetry (PTV). The boundary layer flow field is measured with a combination of acoustic Doppler Velocimeters (ADVs) and recently acquired ultrasonic acoustic profilers (UVP).

Our research team consists of the PI and three Graduate Research Assistants, Juan Exequiel Martin (PhD Candidate) Francisco Pedocchi (PhD student) and Blake Landry (PhD Student). We have also collaborated with Dr. David Admiraal (University of Nebraska) and Dr. Yarko Nino (University of Chile), in the development of Particle-Image-Velocimetry (PIV) techniques to monitor the flow velocity field above sand vortex ripples.

WORK COMPLETED

- *Wave Tank:* Around 40 experiments were carried out in the wave-current flume for both waves alone and combined flow conditions. The main task completed within this effort has been the characterization of the development and evolution of bedforms such as ripples superimposed on larger sandwaves.

- *Oscillatory-flow tunnel:* more than 50 experiments have been conducted to assess mean flow parameters and turbulence characteristics in the tunnel. The calibration of the tunnel is now complete.

RESULTS

Figure 1 shows a schematic diagram exemplifying the formation and time evolution of superimposed bedforms. Ripple formation and steady conditions occur within the first couple of minutes. Formation and migration of incipient sandwaves and finally appearance of sandwaves result after the merging of smaller ones during the first couple of hours in the experiment.

Sandwave geometry parameters such as height, length, and steepness show less, although still important, scatter when plotted against Reynolds wave number *Rew* than when expressed as a function of the mobility number, ψ, or the Shields parameter, θ. Both sandwave length and height decrease as the Reynolds wave number increases (Figs. 2 and 3).

Preliminary analysis suggests the existence of a simple relationship between the sandwave length and three easily measurable variables associated with the surface wave, namely, the period, wave length and wave height (Fig. 4). Measured data for both waves alone and combined flows adjust well to a common trend.

Dimensionless sandwave migration celerity increases as the Reynolds wave number increases (Fig. 5). This implies that larger bedforms migrate slower than smaller bedforms. Vertical growth rate of sandwaves was also measured. Results show that this quantity varies over time (Fig. 6) and is practically the same under varying flow conditions (Fig. 7). Ripples superimposed on sandwaves vary in size, shape and migrating speed depending on their relative location over the sandwave (Fig. 8). It was commonly observed that ripples over the crest are larger and faster than their counterparts located over the troughs. This variation in size and shape can be explained by the variation in wave velocity which is larger over the crests than over the troughs.

Measured ripple length and height are found to be in good agreement when compared to experimental data from the literature. Such formulae for prediction of geometric characteristics, length and height,

are found to depend on the mobility factor ψ and the orbital wave amplitude, a. A strong dependency was found when expressing ripple length and height as a function of the Reynolds wave number Rew (Figs. 9 and 10). In light of this, two new predictive expressions for dimensionless ripple length and for dimensionless ripple height are presented being $l_r/a = 277.3R_{ew}^{-0.55}$ and $h_r/a = 155.2R_{ew}^{-0.68}$, respectively.

Measured ripple speed over the crest of the sandwave (likewise those located over the troughs) show defined increasing trends on both the Shields parameter and the mobility number. Ripple migration speeds are of the same order of magnitude as those observed under regular and irregular waves by other researchers (Fig. 11).

Bathymetric data for sandwaves with superimposed ripples and the associated flow field along the centerline of the wave tank are shown in Figure 12. Figure 13 shows vertical velocity profiles observed inside LOWST with the help of ultrasonic velocity profiles, during the calibration of the tunnel. Figure 14 shows bathymetric data in the wave tank after reducing the reflection of the waves at the end of the tunnel. Notice the absence of large sanwaves.

IMPACT/APPLICATIONS

This is one of the first studies where the characteristics of ripples superimposed on larger sand waves have been addressed. These measurements are extremely complicated to be carried out under field conditions.

RELATED PROJECTS

Collaboration with modelers and field experimentalists involved in this DRI initiative on ripples is ongoing. The observations made in LOWST should prove useful for the calibration, validation, and improvement of existing and future computational models for ripple dynamics and associated flow and sediment transport conditions.

AWARDS

Professor Marcelo Garcia received the 2006 Hans Albert Einstein Award from the American Society of Civil Engineers (ASCE).

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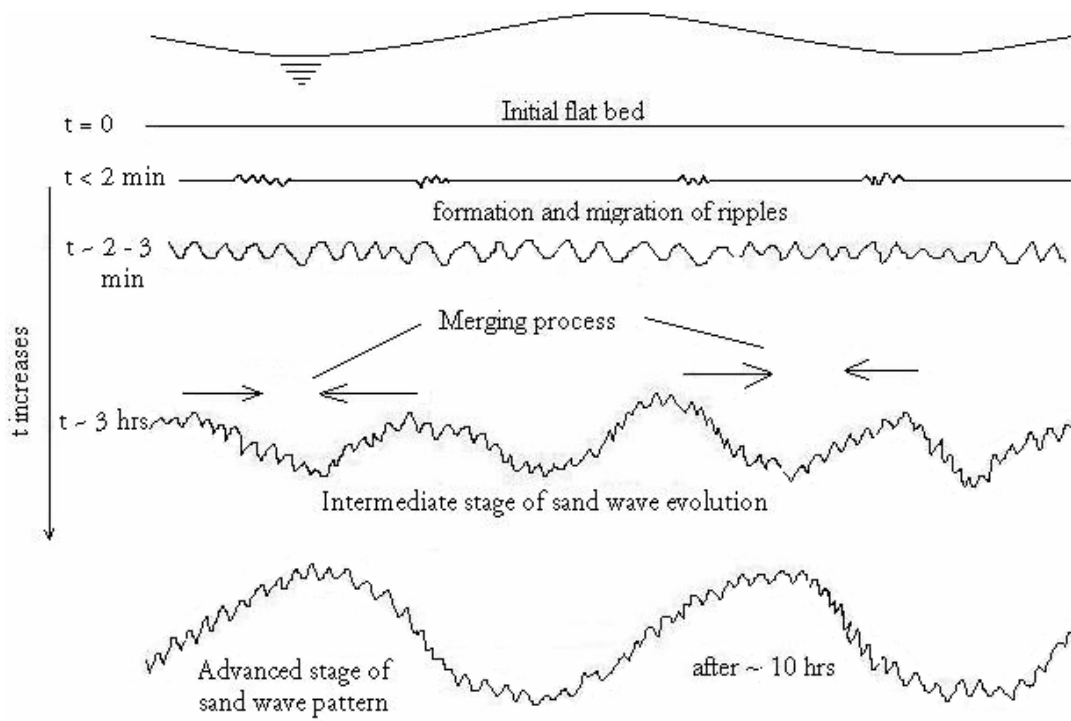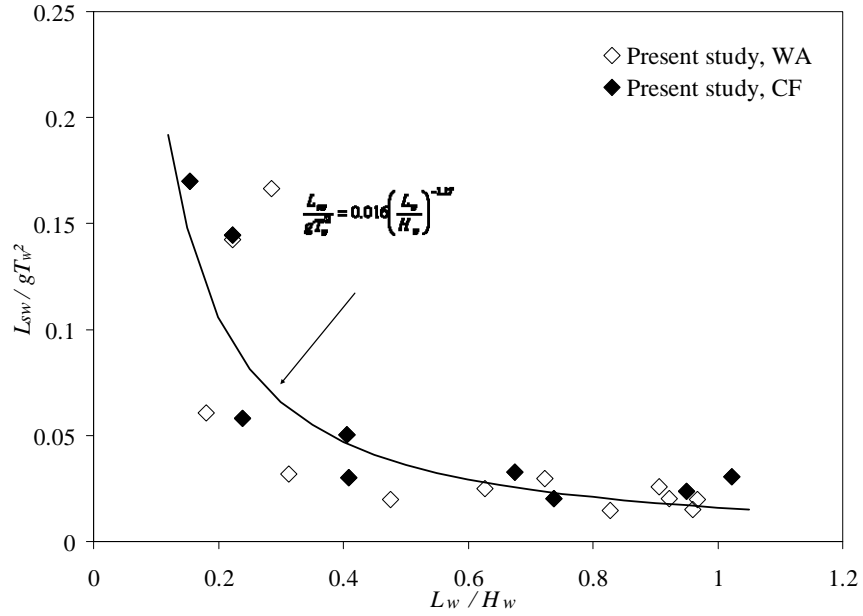
Fig. 1. Formation and evolution of bedforms over time under waves alone and combined flows.

$$h\,sw/a \,=\, 175.76 R\,ew^{-0.54}$$

$$\rho^2 = 0.34$$
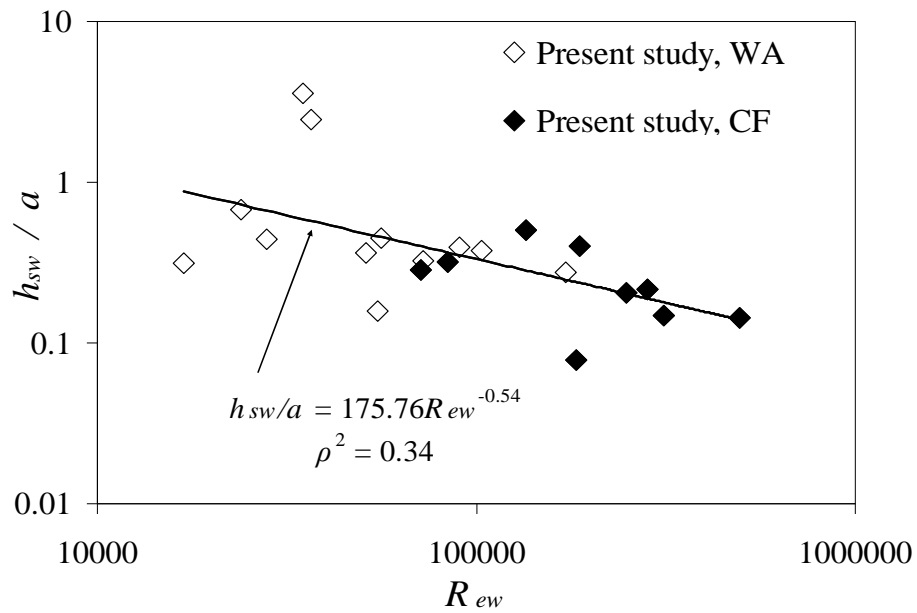
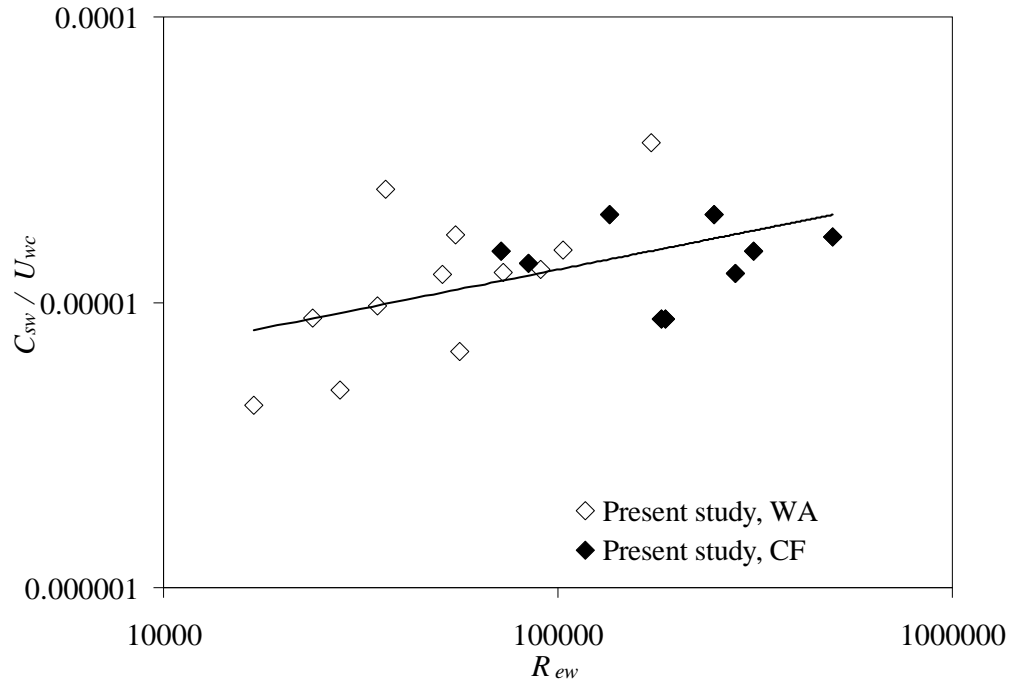*Fig. 2. Measured dimensionless sandwave height as a function of the Reynolds wave number.*
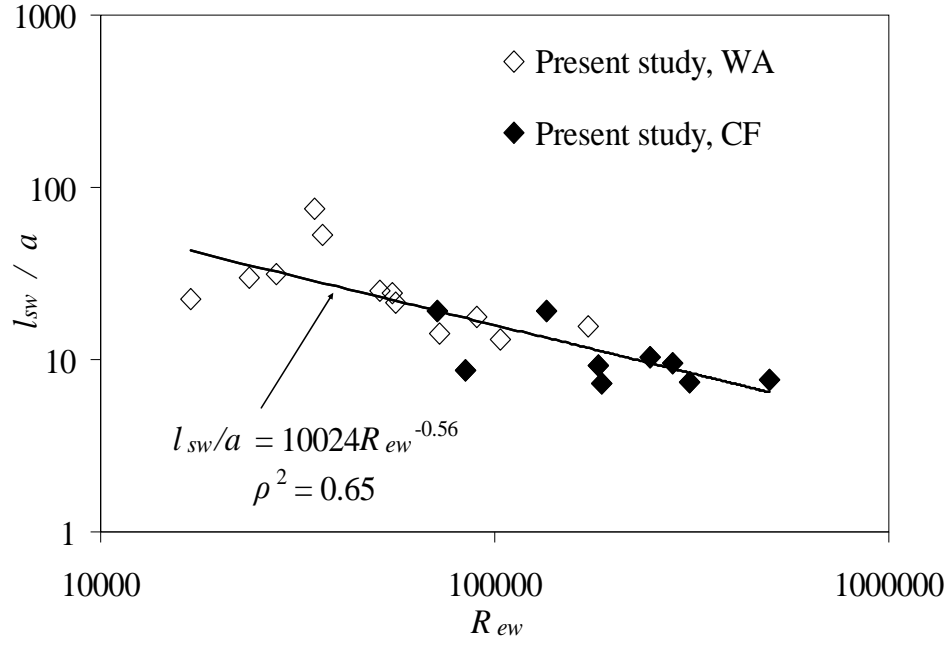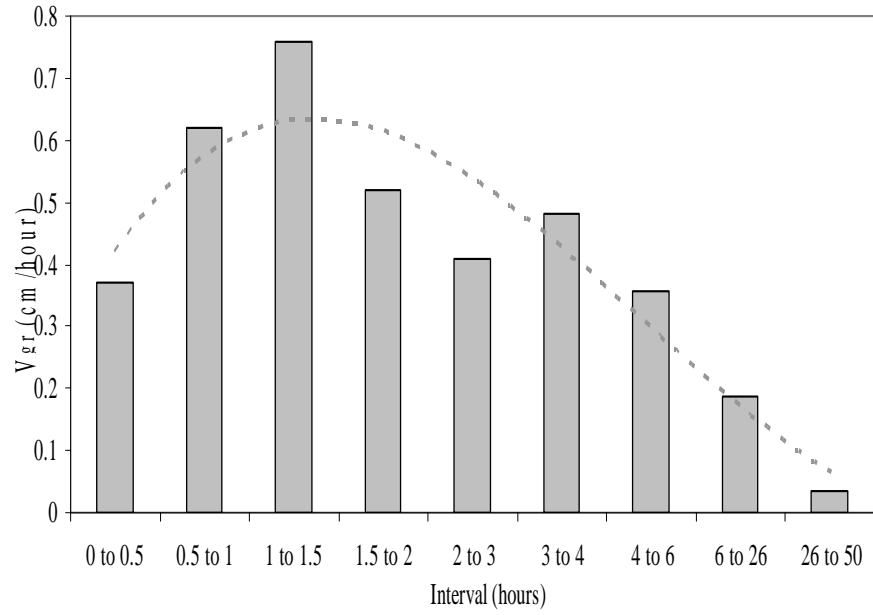
**Fig. 3. Measured dimensionless sandwave length as a function
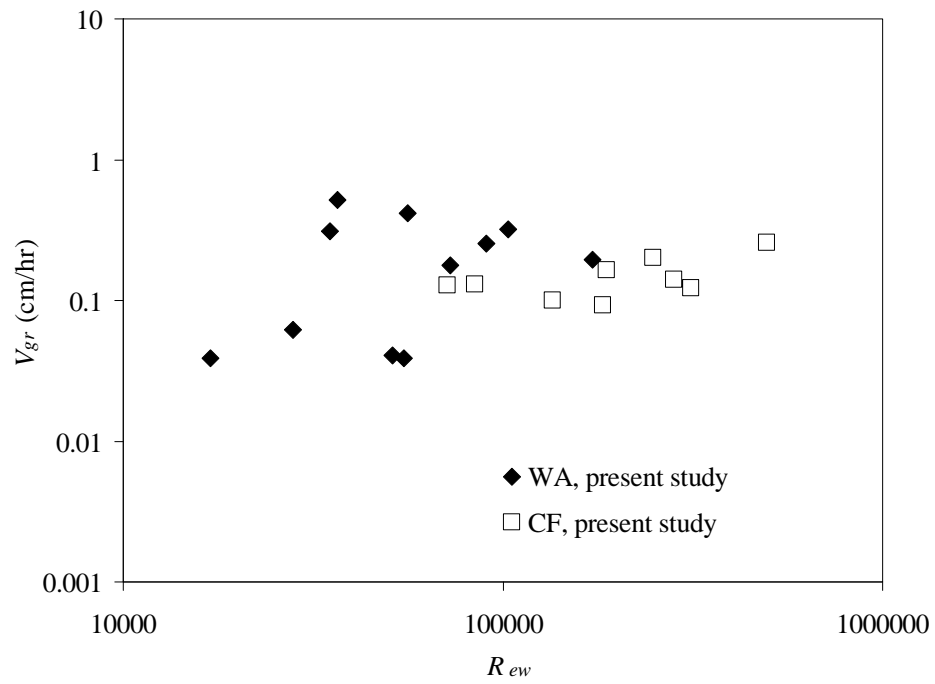of the Reynolds wave number.**

**Fig. 4. Dimensionless sandwave length as a function
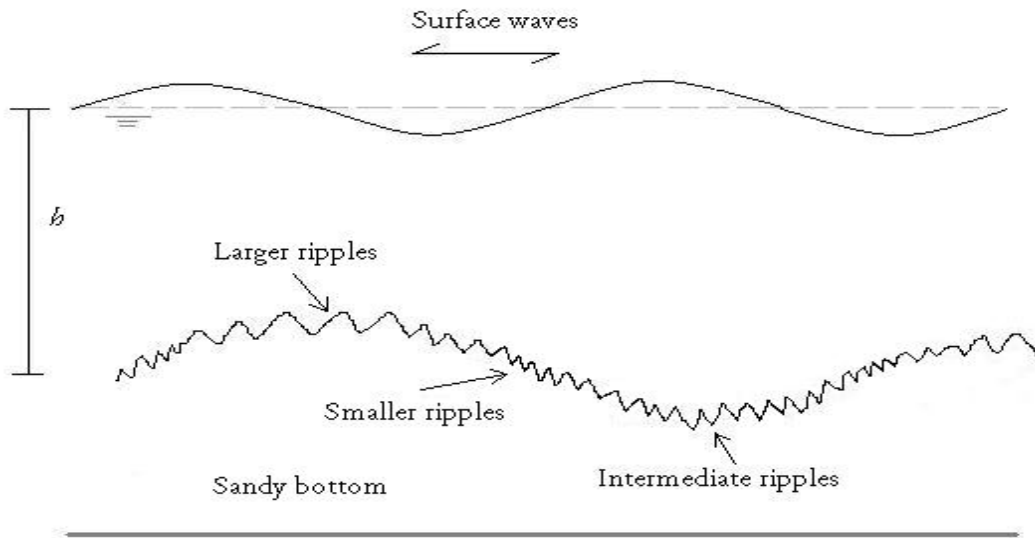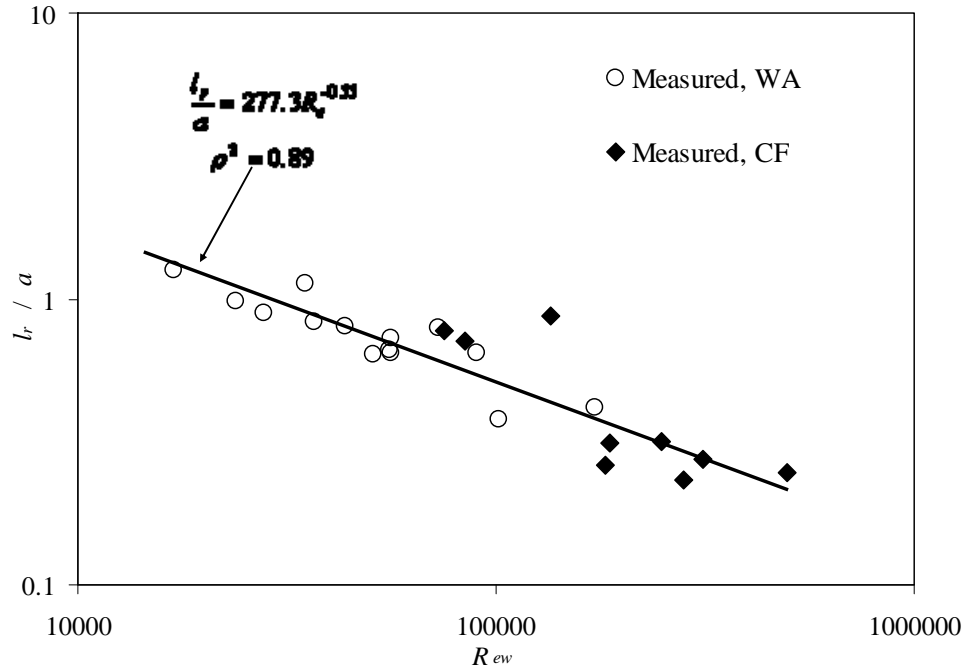of the dimensionless wave length.**

Fig. 5. Measured dimensionless sandwave migration speed as a function of the Reynolds wave number.

Fig. 6. Vertical growth rate of sandwave as a function of time. Case of waves alone.
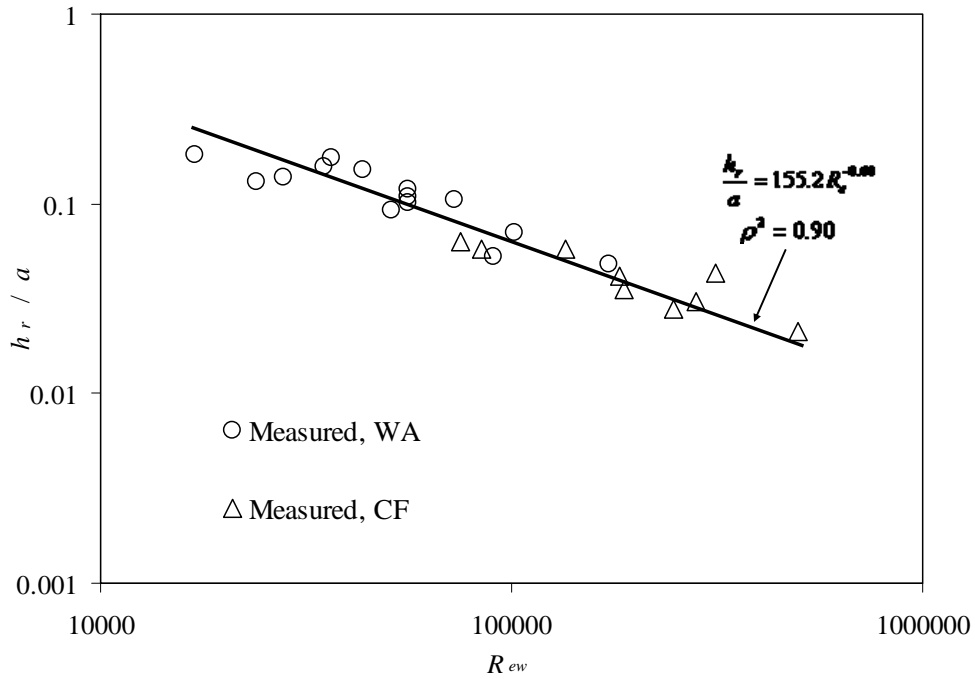
Fig. 7. Measured sandwave vertical growth rate as a function of the Reynolds wave number.
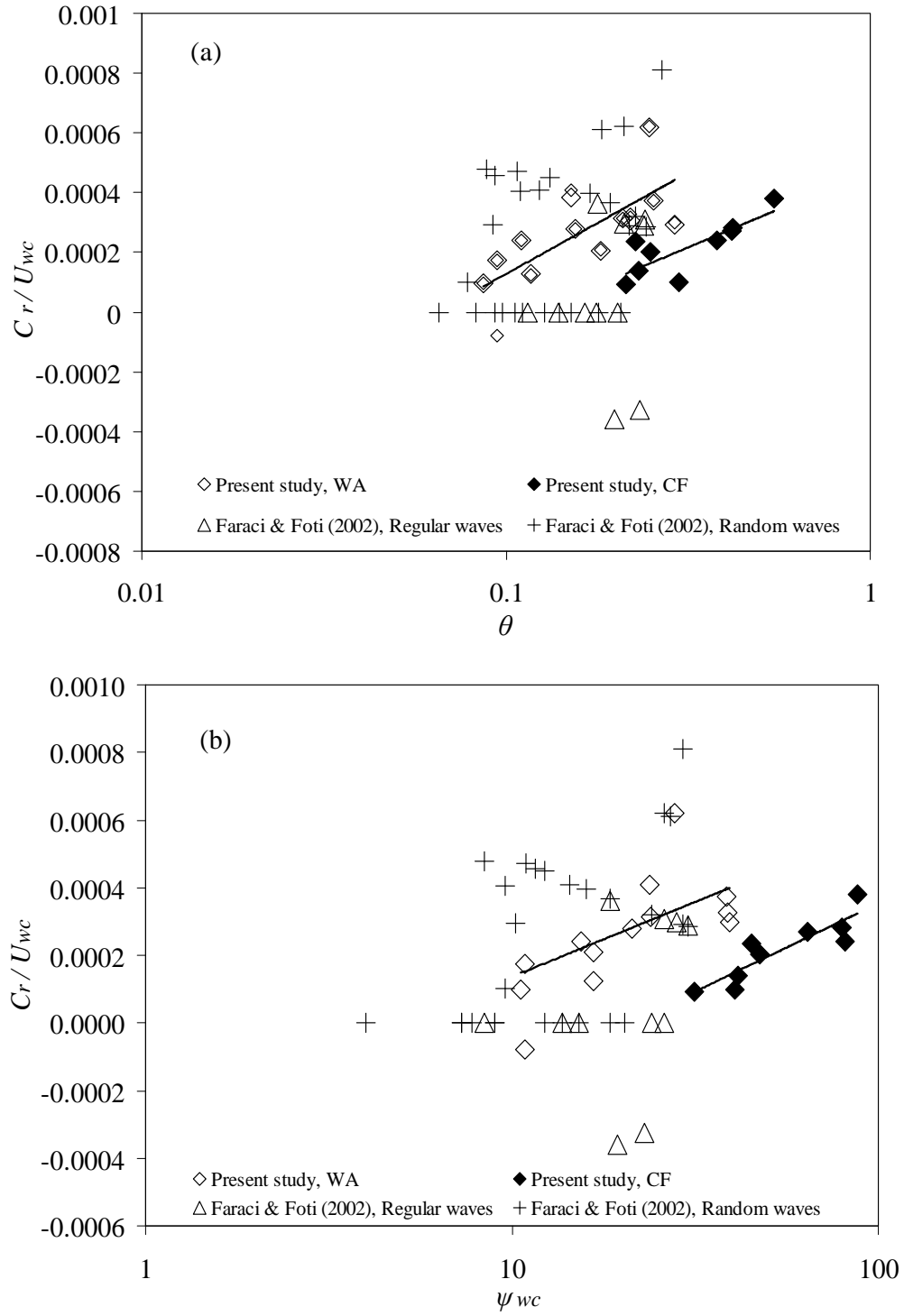

*Fig. 8. Illustration of variation in size and shape of ripples superimposed on sandwaves.*

Fig. 9. Dimensionless mean ripple wave length as a function of the Reynolds wave number defined as Rew = Uwc a / v. Continuous lines represent the fit data measured in this study.
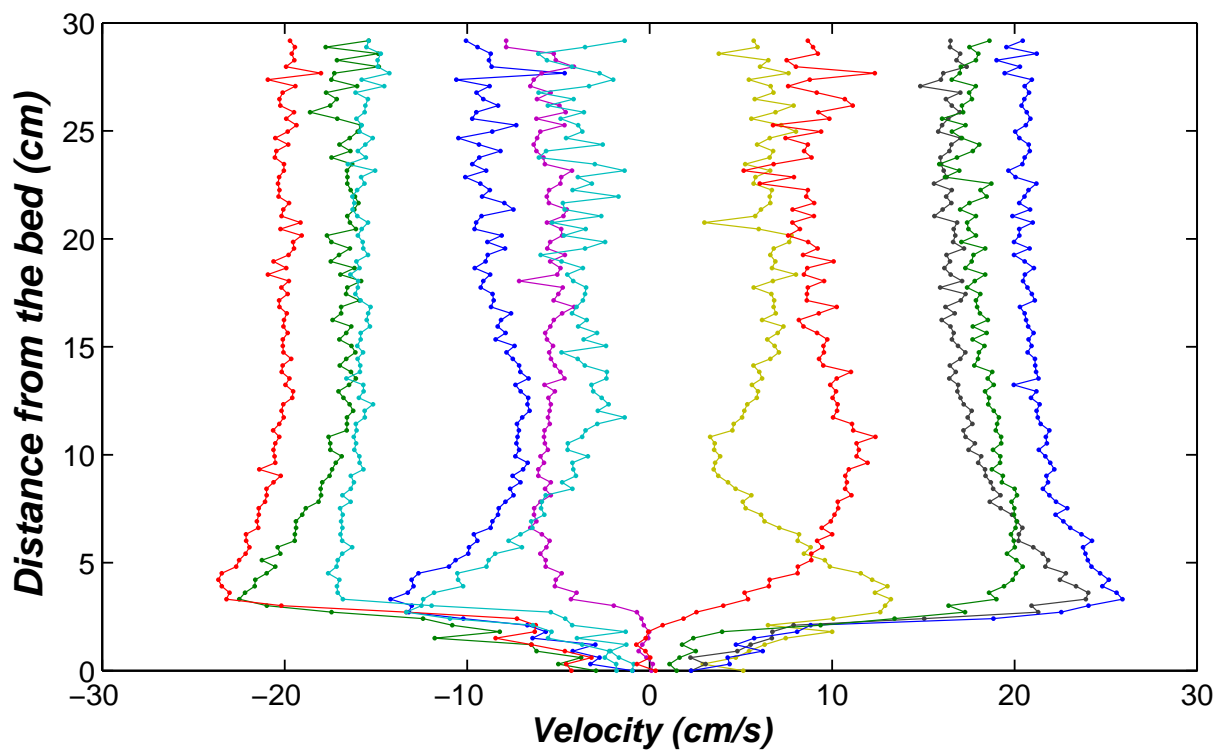

***Fig. 10. Measured ripple height as a function of the Reynolds wave number.***

***Fig. 11. Measured dimensionless ripple speed as a function
of (a) The Shields parameter; (b) The mobility number.***
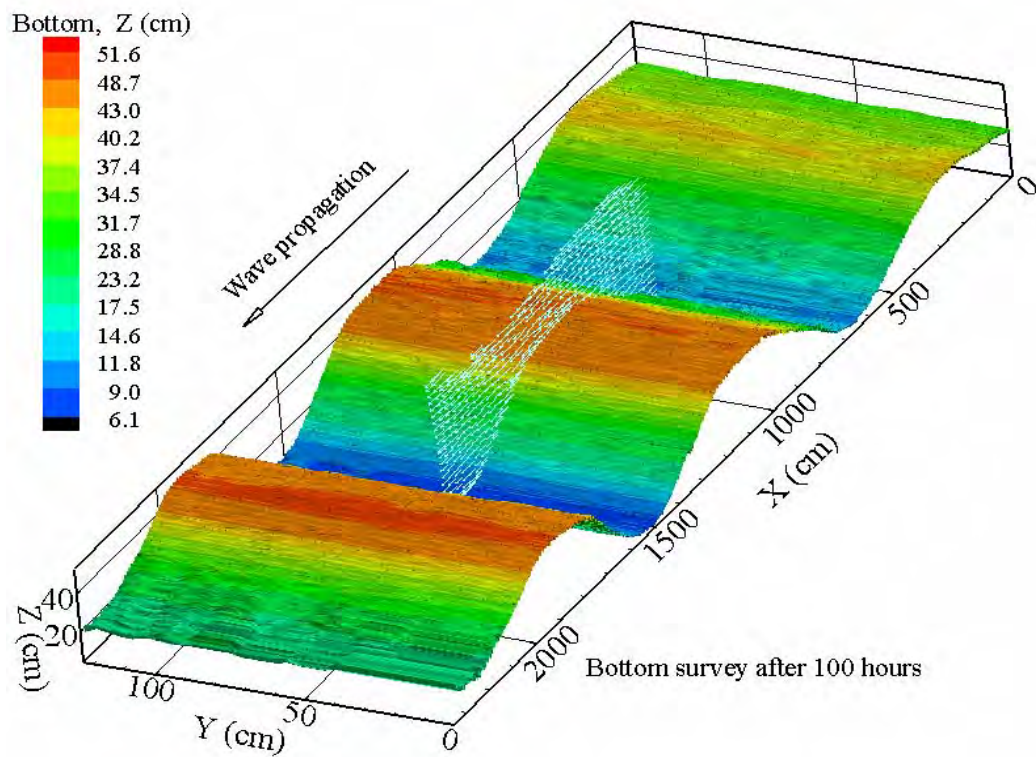
Figure 12 Contour map of the sandy bottom and velocity vectors along the centerline of the center sandwave.

Figure 13 Mean velocity Profiles Measured in LOWST with Ultrasonic Velocity Profilers
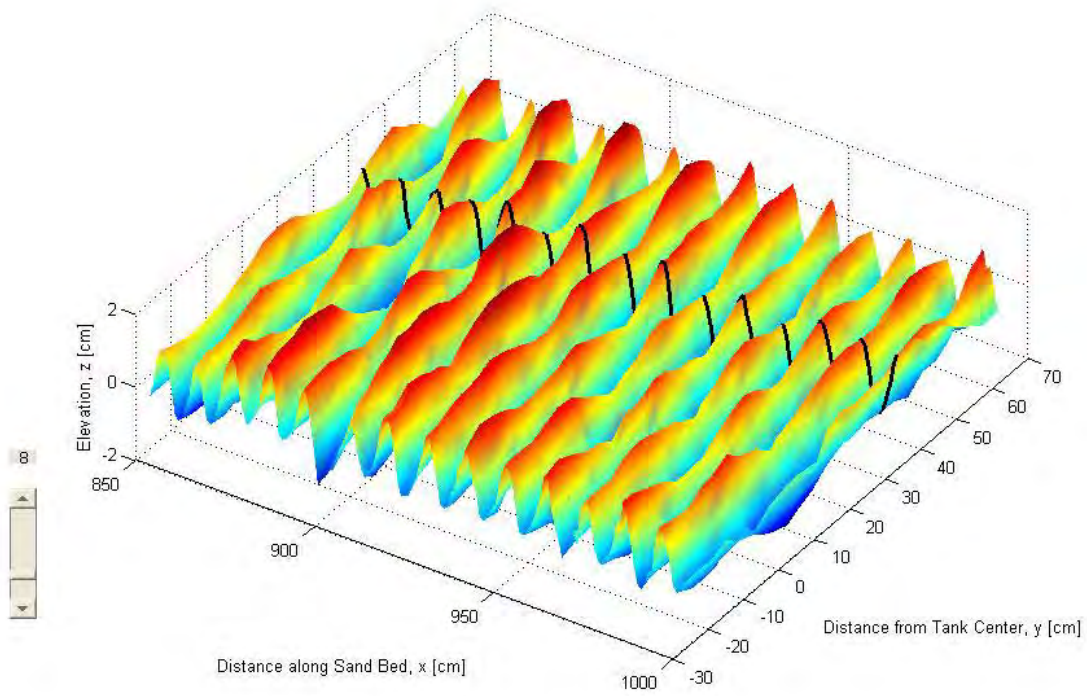
***Figure 14. Ripple morphology in wave-current tank obtained
with the SeaTek transducers***